CONSTITUTION OF THE SUN.

LECTURE BY PROF. C. A. YOUNG.

THE TRANSIT OF VENUS AS A MEANS OF MEASURING THE DISTANCE AND SIZE OF THE SUN—STRUCTURE OF THE SUN'S SURFACE—CHARACTERISTICS OF SUN SPOTS—THE CHROMOSPHERE AND THE CORONAL APPENDAGE.

The heavy storm of last night did not prevent the usual audience that has been drawn by the American Institute lectures from gathering to hear the last of the series, "Our Present Knowledge of the Sun," by Prof. Young of Dartmouth College. He is a rapid speaker, but rarely referring to his notes, never attempting any eloquence other than that which simple diction and a clear distinct utterance confer. His manner impresses the belief that he is a close thinker as well as a careful observer; slow to accept upon his mind, and not in the least in haste to accept doubtful propositions; but when convinced by satisfactory proof, then no longer open to doubt. Hence, when he says "the things we know," or "I know exactly what I am talking about," he carries a conviction of truth to his hearers not often attained by those who expound modern discovery. He is at home with his audience, and from time to time gives a facetious turn to the drier portions of description, that sends a ripple of smiles across the hall, and not unfrequently brings down a round of applause. For the rest, he is a compact, alert, busy-looking man, who would be far more likely to be taken for an active merchant than for a celebrated astronomer.

THE LECTURE.

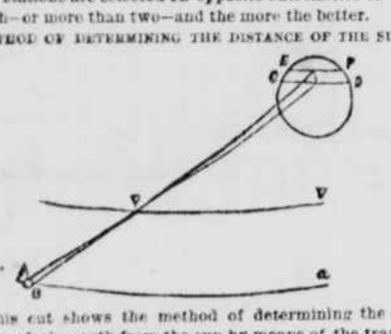
No introduction, I am sure, can be required of me in speaking to you who, coming through such rain and storm, are present on this occasion. I am now to set before you our present knowledge of the sun. This body is not only the center of the solar system, and, by its great attractive power, the controller of the planetary movements, but it is a more important source of all energy, activity, vigor, and vital power.

Modern science traces to the sun almost the whole range of terrestrial activity. We can easily follow out the solar action in our winds, and no less easily in our waterfalls. The pumps that raise the water to the hills are the sun. The power that is expended in intercepting water in its downward flow is at the expense of the solar fire. In a more remote way we may trace to the sun the steam power, which is derived from fuel. The power employed in building up organic structures, taking the carbon and hydrogen from the elementary compositions, and building them up into organic bodies, is derived from the sun. Burning a stick of wood, as Stephenson said long since, is using bottled-up sun at second hand—resuming the power derived from the sun. So all animal power is maintained by the use of organic food. Animals cannot be kept alive on our mineral food. The very force with which we move our limbs, the sound of our voices, and I may go further and say that the power of mind, the impulses exerted in forming thought, in exciting emotions—this is sun-derived, when traced to its ultimate source. Not all, but in great part. Each star contributes its quota, and there are other slight sources of heat, but the greater part of all this power is sun-derived.

DISTANCE THE FIRST ELEMENT.

The whole scientific world, at least the astronomic world, is engaged in investigating the sun and its relations to the earth—its own nature and its relations to terrestrial activities. The first point to be ascertained in relation to the sun, or, indeed, to any of the heavenly bodies, is its distance. There is no difficulty in determining the relative distances of the bodies in the solar system. Kepler's third law supplies a means of determining, but with accuracy, but it supplies only the relative distances of the bodies in the solar system; and other methods have long been known. But to ascertain the actual distance in miles is a problem which until the last century defied all the efforts of science. The ancients invented curious methods, but they all failed practically. The method most relied on, though there are five or six other methods used, and perhaps some of them may in the long run turn out as valuable as the method we rely upon, is by means of the transit of the planet Venus. We will show a diagram on the screen indicating how the observations are thus arranged. Two stations are selected on opposite extremities of the earth—the more the better.

METHOD OF DETERMINING THE DISTANCE OF THE SUN.



[This cut shows the method of determining the distance of the earth from the sun by means of the transit of Venus. In it A and B represent stations on opposite sides of the earth, and a portion of the latter's orbit; V represents the planet Venus, and s shows a portion of its path. C D and E F represent the apparent paths of the planet across the sun's disk.]

SUN'S DISK SHOWING TRANSIT OF VENUS.

[This diagram is a copy of the one shown on the screen and represents the apparent paths of Venus across the sun's disc during a transit, as viewed from stations on opposite sides of the earth. The upper line represents the planet as seen from the Southern hemisphere, and the lower light circle the planet as seen from the Northern. The arrow shows the direction of the motion.]

Prof. Young described the manner in which the distance could be ascertained. When the second diagram was shown, Prof. Young explained that it was intended to show that the appearance would be as seen from a northern station on the earth's surface, say in Japan or Kamschatka. The planet will strike the eastern side of the sun's disk near the northern edge and will pass obliquely along the two lower lines, occupying about 2½ hours. As seen from Japan it will pass along the upper of these two dotted lines. At any given moment the planet as seen from the southern station will be represented by that black spot. At the same moment the edge of the sun as seen from the northern station would be along the rim, and the problem is, somehow or other to compute in seconds the distance between the center of that black spot and this rim, and to a very great degree of accuracy. An error of a hundredth part of a foot at a distance of about 40 miles would make a serious error in the accuracy of our present measurement.

STATIONS IN BOTH HEMISPHERES.

The earth must be regarded as seen from the sun the moment when the planet strikes the disk of the sun, provided an observer on earth were at its center. At that moment suppose yourself transported to the sun looking toward the earth. This will show the apparent path of the earth. There are very good stations, you see, for observation must be set around the edges of the world. You want to be as far from the center of the earth as possible. In the Northern Hemisphere—all along in Japan, Kamschatka, Siberia, China, and Siam, even into Hindostan. But in the Southern Hemisphere we can with New-Zealand and a number of small islands in the Southern Ocean. Of course during the first four hours of transit the earth will revolve considerably. You see that we can by far do better the eastern edge of the sun. There the southern part of Africa will come into the view, and stations will be occupied in Northern Africa.

METHODS AND INSTRUMENTS EMPLOYED.

We have then to find this distance. There will be three different methods pursued. The old-fashioned way was to note when the planet first strikes the sun, and when it leaves it, from which we may know the number of hours it takes to pass across the disk of the sun. This at the northern station gives the length of the chord which it passes over, and the same at the southern station. This was the method of Sir George B. Airy, the Astronomer Royal of England. The main difficulty is this: A bright object looks to the eye larger than it is, and a dark body looks smaller than it is. When the two objects come together they are joined by a sort of ligament, and it is difficult to determine the precise moment when it breaks, so that the observations are very erroneous. Encke deduced from them a distance of the sun which is three millions of miles too small. Another method, which will be relied on by the German astronomers, is to measure the position of this black spot with reference to the edge of the sun by means of the heliometer, an instrument by which we can measure very accurately the distance of the little round spot from the edge of the bright circle on which it will be shown. The other method, which will probably be used by all the nations, but will be mainly relied upon by the French and the Americans, is by photography. The English will use a common telescope, driven by clock-work, with an eye-piece to enlarge the image of the sun to about four inches in diameter. With this they will take photographs of the solar disk from moment to moment while the transit is going on, and they will afterward measure those photographs. The objection to the method is that the eye-piece used to enlarge the image introduces a distortion, which will produce an error that cannot be certainly corrected. The Americans propose to photograph the round image as formed on the glass plate, with a telescope of 40 feet focal length, and to measure it afterward by means of a scale of equal parts. The Germans will use a telescope with a glass plate very carefully ruled into squares, which will be photographed together with the image, and the lines will be measured afterward. I think that method will succeed very well; it is perhaps the best method of all. Lord Lindsay's party from England will use the telescope of 20 or 40 feet long, and I think the method will be well pursued by the French and all. Of course, such a telescope would be mounted horizontally, with a mirror to reflect the sun's rays into it, though that is not essential—and to throw the image of the sun into the object-glass by means of a great dial. It is very difficult to make a mirror flat, but it is the difficulty in that matter; the mirror must be so perfect that it shall keep the curvature equal a radius of 18 miles; for any such point would make the result comparatively valueless, adding very little to our present accuracy.

NATIONAL EXPEDITIONS.

The different Governments of the world are taking hold of the matter with great earnestness. Russia will establish 25 stations in her Siberian dominion, some of them armed with heliometers, a few with photographic instruments, and some proposing to observe the moments of contact. France, even in her crippled condition, is unwilling to fall behind other nations, and will send expeditions to Palestine, the Red Sea, Peking and Japan, the island of St. Paul, New-Caledonia, and possibly to the Sandwich Islands. The Germans will send to the Falkland Islands, McDonnel's Island, and Kerguelen's Island, in the Southern Hemisphere. The English will send to Oahu, to Roderick's Island, to the Falkland Islands, and to Alexandria, in Northern Egypt. Lord Lindsay, one of the scions of the English nobility, who takes a great interest in science, is to send a private expedition of his own to Mauritius, which I think will be more perfectly equipped than those of any Government. He proposes to employ all the three methods—photographing by reflection as well as by refraction, the heliometer, and observation of contacts. The United States proposes to establish eight expeditions. The points are not yet fully determined upon. Four of them will be in Japan and China, and the other four in New-Zealand, the Falkland Islands, Van Dieman's Land, and possibly Kerguelen's Island. I need hardly say to this audience that we may pride ourselves upon the fact that our Government is taking a position among the nations in the encouragement of scientific investigations of this kind. I think I can show you how very important it is to see it, although I should take a higher ground, for some things that are worth more than money. The way I should show you the money value of this point of the national work would be to show how many pounds of the exhibition. Our high schools and common schools pay for themselves in that way, and I think it is our duty to be among the observers engaged in it; and all the intelligent people of the country will read about these expeditions, and they will be engaged in much more in subjects of scientific interest. I think the indirect influence this way will pay the cost of the expedition in a few years; but they will pay directly, for I do not know that anybody will make a cent of money directly by finding out the distance of the sun.

What is that distance? At present we consider it 92,000,000 miles, with a margin of error, we must admit of 500,000 miles; or half of one per cent. We hope by the approaching transits to reduce the margin of error to 250,000 or 200,000 miles; I do not think that is an extravagant expectation. One or two illustrations will aid you to form an idea of the sun's distance. If we should take a railroad train 263 years to move from the sun to the earth; so that if the Pilgrim Fathers had started from the sun at the time they stepped from England, by a train whose only stopping places would be Mercury and Venus, they would not have arrived yet. It would take a cannon-ball, going at full speed, about nine years to make the journey. Light takes eight minutes. Sound, if it could be carried over the celestial spaces, would be 14 years on the way. One more curious illustration. You know that if you touch a part of the body, one does not feel it instantly. If you touch the hand of any one with a pin, it will be an appreciable part of a second before he will feel it, and draw his hand back. Now if I had an arm long enough to reach the sun, and I should put my fingers into the solar flame and burn them there, it would be 100 years before I should find it out, and another 100 years before I could remove my hand. [Great applause.] Such is the distance of the sun, so great that space the earth responds to every impulse of the solar surface.

DIMENSIONS AND DENSITY OF THE SUN.

Once having obtained the distance of the sun, it is very easy to find out its diameter, which is about 860,000 miles. If the earth were represented by a ball 2¼ inches in diameter, the sun would require a ball of 18 feet in diameter, which would just about lie between this stage and the ceiling. If the earth were placed at the center of the sun, the moon would be so far inside the sun's surface that there would be almost room for another moon beyond, the distance of the moon from the earth being 240,000 miles, and the surface of the sun from its center 430,000 miles. In bulk, the sun is a million and a quarter times larger than the earth; that is, it would take that number of earths rolled into one to make up the bulk of the sun. It would not take that number to make up the weight of the sun, for the sun is lighter, bushel for bushel, than the earth. It weighs about 325,000 times as much as the earth. With that enormous mass, the force of gravity must be 28 times as great at the surface of the sun as at the surface of the earth; so that a man, and I am not very big, I should weigh about two tons on the sun, and I think the most graceful of our children would be crushed. Comparing its light density with its bulk, we are led to the important conclusion that the sun cannot very well be either solid or liquid at its center. It is doubtful whether there is any solid or liquid matter about it, in the ordinary acceptation of the term. There is probably a mass of gas. The probability is that the center of the sun is nothing more than a mass of gas, so intensely heated, and by pressure kept from expanding, that the sun is a body of great tenacity, and that heat resisting the compression of the force of gravity, so that the gas becomes of a density greater than that of water. Air has been condensed by artificial means on the surface of the earth so as to be as dense as water. That is the sun's probable constitution, but is probability and not certainty.

TEMPERATURE OF THE SUN.

The sun is very hot. The most direct evidence we have is, I think, the action of a burning glass, which virtually removes the object in its focus nearer to the source of heat. An absolutely perfect burning-glass would put an object in its focus in contact with the source of heat. If we put paper or gunpowder in the focus of a burning-glass it is inflamed. The effect is virtually to move the object toward the sun until its angle viewed from it is the same as the angle of the glass. If we could conceive of a burning-glass so large and perfect, we could not quite realize, because the glass absorbs a part of the heat; but we have in this way, by the best of burning-glasses, brought the object to a distance of the sun of a distance of 250,000 miles from its surface. The heat at that distance is as great as that we know at even at that distance platinum melts down like wax, and the heat exceeds that which we can produce in any other way, except by the voltaic arc. There is no question, therefore, that if the earth were to be drawn as near to the sun as the earth is to the moon, the earth would be volatilized, and all its substances turned to vapor. The sun has, of course, a very high temperature, but how high I do not know, and I do not believe anybody knows. We have had very different estimates. The French physicists have estimated it to be very far above the heat of the electric arc, as comparable with it, on the upper part of the scale. Secchi estimates it at 2,000,000° Fahrenheit, and Ericsson of this city at 4,000,000° or 7,000,000°. The sum of all our information is an attempt to carry laws which are only approximate, obtained from experiment, and known only to be approximate, through an enormous range. The experiments carry these laws into regions beyond the point that black spot and this rim, at any rate, an attempt to decide between them.

HEAT EMITTED AND ITS SOURCE.

But, although we cannot measure the temperature, we can measure the quantity of heat given out by the sun, which is a very different thing. The unit of heat, as any quart of heat, is that required to raise one pound of water one degree; or, if I were French, I should say one kilogram of water. Or we may take another unit, which I may call a bushel of heat, the amount of heat which a bushel of coal would give in burning. There is a definite quantity of heat. One that we can measure from the sun at the present time. Sir John Herschel found by his experiments—and Fourier agrees with him—that the amount of heat emitted by the sun every hour would melt a shell of ice 40 feet thick about the whole sun. Sir John Herschel illustrates it in this way: Suppose ice should be drawn into a rod forty-five miles in diameter, and thrust into the sun at the velocity of light, if all the heat of the sun could be concentrated upon the point of that advancing javelin of ice, it would be melted as fast as it came. Or we may put it in another way: Suppose we should build a railroad from the sun, 30 feet in diameter, at 12 miles square of solid ice, carrying it at a rate of one mile a second, and cast it into the sun, it would fall so fast as to pass, with Mercury, and Venus, and it would be volatilized, changed into steam vapor.

Such is the solar fire. What maintains this heat? It is a question I cannot answer. The heat of the sun has not been derived from the past. Whether the sun's heat has altered during the last 2,000 years or not, we have no direct evidence, so far as I know. The vine grows where it grew 2,000 years ago, and the wheat with. There have been small changes of climate, in one part of the world or in another, but all not in any one direction. There is no evidence that the sun has been progressively hotter or cooler. In geologic epochs, there may have been no such progressive alteration in the amount of heat given off by the sun.

AN UNKNOWN SUPPLY OF FUEL.

Of course the sun cannot continue to give off the amount of heat which I have stated without some supply, and we have consequently a great deal of conjecture about the origin of the solar heat. Some have attributed it to chemical combinations; but if the sun were of solid coal, it would have been completely burned out in 5,000 years, to give out heat at the present rate. Some have thought that the sun was cooling. But a body so very large we did not perceive the cooling in a period of 2,000 years. Unless the sun is constituted of very different materials from what we have reason to suppose, it would certainly in that time have cooled. The view that is now generally taken, and which is, I think, in part the proper one, is that the heat is maintained partly by the influx of matter. As meteors fall upon the earth, several millions in a day, so they fall into the sun, millions of them every day, and contribute to the solar heat. But that is not enough to account for it all. Another cause, I doubt not, is the contraction of the sun. If the sun were to contract 120 feet in radius, or 240 feet in diameter, in a year, it would give off heat enough to maintain it without growing colder. If bodies may give off heat without growing colder, if we freeze a pail of water, it gives out heat while it is freezing. The thermometer will indicate no fall of temperature until it is all frozen. So it is quite likely that the gases in the outer surface of the sun will enter into combination with each other, and give out heat. It will be in that way, that we have this contraction going on, and uniting in this process of shrinkage I imagine that the sun is undergoing. But I do not know. Yet I would speak very cautiously about it. I do not know anything about it. It is almost wholly conjecture.

A LAYER OF CLOUDS.

Next I will speak of the physical appearance of the sun. Constituted, as I suppose it to be, the vapors in the outer portion of its atmosphere would naturally become condensed, and form clouds. As in the upper regions of our own atmosphere the vapor condenses and forms clouds, so in the sun, there would undoubtedly be clouds, and there might be drops, the different gases being condensed from liquid to form, not into water, but iron, copper, silver, &c. The appearance of the sun warrants this conclusion. In the telescope like a mass of clouds. It looks very much like curdled milk, or like cotton wool. This surface of the sun is mottled in this way. It is much darker on the edges, which is a very important point in explaining its constitution, and there are also numerous bright streaks, called faculæ, besides the solar spots, of which I shall speak in the regular course of this lecture. Mr. Nasmyth thinks that these irregular forms resemble willow leaves. I have not seen that, but I have seen in the sun what seemed irregular masses, dark spaces, and here and there apparently little holes.

PECULIAR ASPECTS OF SUN SPOTS.

The bright spots, called faculæ, are elevations on the solar surface. But the most remarkable objects on the surface of the sun are the spots; they are far more striking than the faculæ, and this one (pointing to diagram) may be taken as a good example or type of such spot, fairly formed, and well established. In the center of it is a dark spot looking like a hole. The holes in the center are not uniformly dark, there are usually little bright edges; about the umbra is a little broader belt, the penumbra, and the edges of this are sharply defined, with no shading. Around this center, called the umbra, there is a wide border called the penumbra, almost always radial in its structure, sometimes with radiating edges, and striped radially. This hole—the umbra if it be a hole—is so large that the earth might be dropped through into it without touching its edge. It is over 12,000 miles in diameter. The faculæ are always grasping by reflection the penumbra. Where the faculæ come to the edge, there is a little projection.

Here is a diagram illustrating the spot observed by Secchi in 1866, as seen as it was formed. Everything was in confusion; a dark place beginning here, and another here, and then a bridge, and here a whirl of another here, and there things are even more confused, and there is no evident construction. It was 4,000 miles long. The next day, after 24 hours, the spot was drawn out and became narrower and long. The sun rotates forward with reference to the rest of the solar surface, and the spot itself undergoes change of form. It jumps forward with reference to the rest of the solar surface, leaving a trail behind, as it something was dragging through a resisting medium.

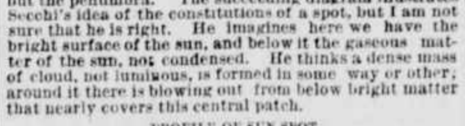
CHARACTERISTIC SUN SPOTS.

[These are sun spots observed by Secchi. The upper one was observed Sept. 25, 1865, and shows the well marked spiral character of these phenomena. The second was observed July 30, 1865, and is characterized by the number of nuclei. It also shows the formation of a spot. The third was seen by the same observer Sept. 23, 1866.]

The next diagram shown by the Professor illustrated the spiral motion not unfrequently seen in the umbra, indicating well-marked spirals with a bridge drawn from a facula over the umbra and irregular bridges passing away over the penumbra. Then followed in rapid succession a diagram of a large spot, with not a very well marked penumbra, and here and there red clouds which were almost certainly prominences. This was taken before the spectroscope was invented, and astronomers were not able then to observe these hydrogen flames properly.

As to the nature of these spots, it is absolutely certain that the dark centers are depressed below the solar surface, but whether they are holes through to the body of the sun is another question, but they are cavities when a spot is first formed. You do not see the umbra, but the penumbra. The succeeding diagram illustrates Secchi's idea of the constitutions of a spot, but I am not sure that he is right. He imagines here we have the bright surface of the sun, and below it the gaseous matter of the sun, not condensed. He thinks a dense mass of cloud, not luminous, is formed in some way or other; around it there is blowing out from below bright matter that nearly covers this central patch.

PROFILE OF SUN SPOT.



[The cut represents a vertical section of a sun spot, according to Secchi. On either side is seen the bright surface of the sun raised, the dark part of the spot being depressed in the middle.]

The lecturer next explained a number of exceedingly beautiful diagrams. There were two, representing the same spot at different dates. They were taken at Dartmouth College Observatory on March 20 and Feb. 28. They had considerably altered, and the bridges were made horizontal, which the lecturer said is proof absolute that we have to deal with something like cloud, as no solid would change its shape in that way. There is a number of photographs taken by Mr. Rutherfurd of this city, showing the dark nuclei with penumbræ, the spot as forming next day, with its train, and new penumbræ on either side. Next day the spot had separated and a little streak of light had formed. Next day it was fully developed, illustrating how spots change their form, their materials moving with a velocity of not unfrequently a thousand miles an hour. Another of the same series illustrated a spot part formed and the following day divided into two segments. Across the diagram was a broad band, the photograph of a spider's thread, which showed how extremely minute was the picture. With reference to the spots, the lecturer remarked: They are not found alike at all portions of the sun's surface. To talk of temperate zones in a body as hot as the sun seems strange, but the spots are found in the temperate zones. They are not common in the sun's equator, or more than 30° from the equator. Rare examples have been found at 40° or 45° from it.

VARIATIONS OF SUN SPOTS.

The most curious thing about them is that they are not equally frequent in different years and are regular in their irregularity or periodicity. After appearing in great force, they become infrequent for three years; then they gradually increase in number until, in about ten years from the first period—or maximum frequency—they are again abundant. I said about ten years; the period is somewhat variable, but the difference is not very great. Sometimes as many as 400 or 500 separate groups of spots have been marked upon the sun in a single year, and again there is a year when spots are few, and there may not be more than 80 or 100 in a year, so that in the year of maximum spot frequency, the number is four times as great as on the year of minimum frequency. The cause of this is not yet known, but it is surmised by De la Rue and his associates in England, by Carrington and others, that this is connected with the motions of Mercury, Venus, and Jupiter. I do not think that observations show this to be fairly established. Time, however, will undoubtedly tell if there is any such connection between the appearance of the spots and the motions of the planets. My own impression is that more probably it is a periodical boiling over of the great caldron that gives rise to these spots; and yet it may be possibly due to some planetary action which I cannot well explain.

DOUBTFUL EXPLANATIONS OF THE SPOTS.

The spots are cavities, but whether they are holes through to the body of the sun is another question. Secchi and the French astronomers believe they are orifices through which heated gas is blown out from the center of the sun—or they did hold this view about three years ago, for I do not speak with authority of their present belief. In this way an underfeed is caused from all directions, and this gives rise to the flames of the spot.

But when we come to examine the sun with the spectroscope we find no such motion inward, but we do of outward motion. Under the cloudy surface there is an ocean of liquid, and slags are formed in this ocean, and there is a blowing out of matter, which gives rise to the penumbral phenomenon. There is undoubtedly an underfeed from the outside toward the center, but whether by a rush downward from the center of the spot, I cannot say. The English astronomers believe it is from the outside atmosphere to the center of the spot.

A photograph was exhibited, taken by Prof. Mayer of Stevens Institute, at the eclipse of 1869, of a bright spot first observed in 1842. In another screen picture the spot was more fully exposed. Then a picture taken near Burlington of a spot with an enormous prominence about 60,000 miles high and about 120,000 miles long, generally called the Anvil Prominence, was shown on the screen. On this photograph there was observed a brilliant red star, as seen by the eye, and a very large and beautiful object as seen by the telescope, with a stream running off and the prominence on either side completely covered up. It was during the Summer of the year before this was taken that it became possible to observe these prominences by means of the spectrum. We find the sun continually surrounded by such objects.

A screen picture of a red color illustrated how prominences are seen by the spectroscope, showing a mass of the hydrogen flames of the chromosphere. This was taken last Summer. Another diagram represented Secchi's illustration of the dimensions of the chromosphere of the prominences as compared with the sun; and with the faculæ, showing that the prominences are related to the faculæ.

THE CHROMOSPHERE PROMINENCES.

[This is a representation of the sun with chromosphere and prominences. It shows the relative magnitudes of the latter as compared with the magnitude of the sun, and also their number. The inner circular line is the boundary of the sun proper, as distinguished from the chromosphere.]

These are very beautiful objects, and change their forms as rapidly as clouds. Here is a diagram of some of the different forms that are commonly observed. Father Secchi gave them different names by which to identify the various forms. All these are seen quite common, and are generally noticed in the neighborhood of a spot.

SOLAR PROTUBERANCES.

[These are representations of certain frequent solar protuberances, and show their filamentous character.]

Here are diagrams of other forms. They are very changeable in their shape; one is like an apple tree with a flock of birds around it. Secchi had names for each of these different kinds. It is of no particular use to name them, except that we can sometimes more easily refer to the sort of object we wish to call attention to. They are not always attached to the solar surface, and sometimes connect with it only a little filament or stem. Filaments are sometimes observed reaching out in all directions. The material certainly contains hydrogen, as the line of the spectrum coincides precisely with the hydrogen lines of the spectrum. There are also other lines in the spectrum of the protuberances. Secchi makes a statement, which I do not wish to indorse, that they sometimes appear to be formed at an elevation above the surface of the sun, and to descend upon it, as though the material was driven upward into the solar atmosphere, and there took shape and fell back. I have never seen anything to warrant that. The gas may, however, be driven up in an invisible condition, and then become gradually visible. Although this gas is very hot, we must not consider it as burning. It remains unchanged, like the Burning Bush. It has often been a question with me whether we have really to do always with matter thrown out from the sun in these cases, whether it is not something like gas catching from below. It is impossible to answer that yet.

This diagram shows a curiosity of the solar eruptions. It was from an observation taken last July. Here is a little object very much like the smoke of a steam engine. The changes in these objects are excessively rapid.

CHANGES IN A PROMINENCE.

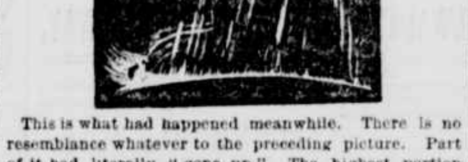
[This diagram and the one below are representations of a solar prominence, seen before and after an inverval of 30 minutes, by Prof. Young, Sept. 7, 1871.]

Some of you may have seen this diagram before. It shows the most extreme case of rapid change observed in any object. It remains as you see it for the greater part of two days. I had seen it on the first day and again on the next, just before dinner. I have my dinner at the good old New-England hour, at noon. I returned in half an hour, and you will see what had happened.

AFTER THIRTY MINUTES.

This is what had happened meanwhile. There is no resemblance whatever to the preceding picture. Part of it had literally "gone up." The highest portion must be regarded as being 200,000 miles above the solar surface. I saw myself particles ascending 100,000 miles in a very few minutes, appearing to go over 200 miles per second, though it must really have been some 400 or 500 miles per second. That velocity would throw iron clear off from the sun, so that it would never return to it. Mr. Proctor says that we may account for our meteoric iron as particles from the sun, thrown out in these explosions.

JET-FORMED SOLAR PROMINENCE.



[This cut shows a jet-formed solar prominence in the neighborhood of a spot, as observed by Prof. Young Oct. 5, 1871. It was estimated by him to be 50,000 miles high.]

This diagram shows the appearance of the neighborhood of a spot. I said a spot was a cavity filled with gases. When that is overlaid with hydrogen, then it often happens that if it is seen through the spectroscope, in the neighborhood of the black spot, you will see a bright one. Seen under the spectroscope, this was white, with a little jet projecting from it, like arches of liquid spouted out from the sun. This was 50,000 miles high. The performance lasted all the afternoon, changing all the time.

Now I come to speak of a different subject. I have been speaking of the hydrogen atmosphere near the surface of the sun. That is not all there is around the sun. When the sun is covered up by the moon, during an eclipse, it is surrounded with a great halo of glory.

APPEARANCE AND NATURE OF THE CORONA.

I will now show you the drawing of the eclipse of 1869 at Sioux City. At first I did not believe at all in the representation which was made of it; but, after seeing the Spanish eclipse, I did see precisely such streaks as those here which I doubted having appeared at Sioux City; and I am disposed to say now that it is a faithful representation of what was seen then. The corona one would probably see is that indicated by this bright portion. The dark spots are originally red, but take dark in the photograph.

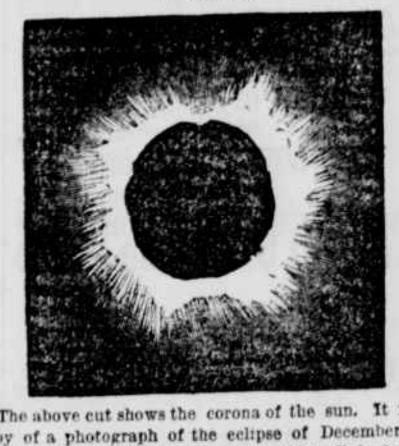
The next diagram is the photograph of the same eclipse as taken at Shelbyville, Ky., by the party under Prof. Winlock's charge. It would have been a matter to establish in itself the solar nature of the corona if it had not been asserted by a good many that, as it was taken with an exposure of 40 seconds, it could not be fairly regarded as the true structure of this halo of light; for you see there would be mixed up in it appearances as they were at the beginning of the eclipse; then some later and some some still later; and as the belief was that these appearances were changing very rapidly, second by second, this could not be taken as a fair indication of the view at any particular moment of the corona. But it was settled that that corona was a solar phenomenon.

THE ECLIPSE OF 1870.

We have the eclipse of 1870, as photographed in Spain by Prof. Winlock's party. This is very different. The reason was simply that that photograph was taken through a partial cloud; that is, there was a light vail of cirrus over the sky. We had continual showers, and not long before the eclipse we thought we should have to take our instruments in, and come home to America a disappointed set of individuals. But at the moment of totality a break in the clouds was just in the right place for us. But there were drifting clouds, and the consequence is a great deal of false light in the picture. What I want you to notice is in each the relation of the prominence and the rift. Compare this with the photograph of the same eclipse as taken in Sicily. Here is the prominence, and here is the rift. Compare the two and it will be found that in almost all their details they coincide. A rift in the corona is always opposite a prominence. That means, of course you see, that the corona must be a solar phenomenon. It is an indication of an enormous atmosphere, an envelope, as it were, of gaseous matter rising to this great elevation above the sun, a distance of one-quarter at least the diameter of the sun; and the photograph does not by any means show the total extent of it. This and the one taken in Spain were not liable to the objections made to that taken at Shelbyville, for in them the exposure was not more than six seconds.

I cannot imagine anything more perfect than these photographs of the eclipse of 1871, by Lord Lindsay's party, in India. Here you see the rifts and these delicate filaments—indeed, they are far more beautiful seen upon the glass than as exhibited here. The filaments are not by any means radial, but sometimes occur like the petals of a flower.

THE CORONA.



[The above cut shows the corona of the sun. It is a copy of a photograph of the eclipse of December 12, 1871, made by Lord Lindsay's party at Baicull, in Southwestern India, near the end of the eclipse.]

You see you have, in a picture taken at the interval of some three minutes later, almost the identical appearance that you observed a moment ago. The differences are minute, showing conclusively that the corona is an enormous solar appendage. As to the construction of the material of which it is composed I cannot say. Mr. Proctor thought for a while that it was merely the exhibition of the shooting stars falling in upon the sun, and forming a mass of volatilized matter. What the cause of this formation is it is not possible to say with certainty. Some think it is mechanical; that these streams are formed by matter thrown out from the sun; others think it is more nearly analogous—and I entertain that view more than any other—to the formation of our aurora borealis. You know how the streams of that form parallel to each other in the same direction as the magnetic dipping needle. Whatever the cause may be, the corona is a most stupendous and beautiful phenomenon; for you have here streams 200,000 or 300,000 miles long, and more or less perfect throughout their length.